Phenology and Spatial Pattern of *Typhaea stercorea* (Coleoptera: Mycetophagidae) Infesting Stored Grain: Estimation by Pitfall Trapping

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ABSTRACT The hairy fungus beetle, *Typhaea stercorea* (L.), occurs frequently in stored grain, often in large numbers. Populations infesting stored barley in Minnesota, corn in South Carolina, and wheat in Florida were sampled by means of grain probe traps. Spatial distribution of the species was examined by contour analysis of trap catch. In South Carolina, corn was sampled at 2 locations over 2 storage seasons, and temperature, moisture content, and malathion residues were measured. These data were used to examine phenology as well as spatial distribution, and showed peak trap catch shortly after harvest in the fall, and in the spring. This pattern followed seasonal changes in grain temperature, but there was no apparent relationship of trap catch to either grain moisture content or malathion residue. The populations of *T. stercorea* were not distributed randomly, but were largely concentrated in 1 or very few aggregations associated with the "spoutline," a region high in foreign material and broken grain that forms near the center of a bin as it is loaded. However, the spatial patterns were dynamic, even on a very small time scale (week to week). Numbers of insects in aggregations rose and fell, the areas involved expanded and contracted, the centers shifted, and secondary centers appeared and disappeared. These changes were apparently in response to changing patterns of grain temperature and moisture content. Secondary centers of aggregation often formed in warmer grain along bin walls.

KEY WORDS *Typhaea stercorea*, hairy fungus beetle, stored grain, phenology, spatial distribution, trapping

THE HAIRY FUNGUS beetle, *Typhaea stercorea* (L.), is a cosmopolitan storage pest that has been recorded from a variety of commodities and habitats (Cotton and Good 1937, Hinton 1945, Strong and Okumura 1958) and occurs frequently, often in large numbers, in stored grain (Arbogast and Throne 1997; Barak and Harein 1981; Horton 1981, 1982; Subramanyam and Harein 1990; Weinzierl and Porter 1990). Although, it is generally considered a mold feeder associated with poor storage conditions, it has also been reported to damage grain (Jacob 1988, Tigar and Pinniger 1996). In either case, it should be considered a pest of substantial economic importance. Its frequent occurrence in large numbers causes contamination and may result in grain being assigned the special grade "Infested" (USDA 1997). Also, *T. stercorea* can act as a carrier of *Salmonella;* and because it can fly, it is capable of spreading the pathogen over long distances (Hald et al. 1998).

Despite its widespread and common occurrence in stored grain, there have been few studies of its biology. Jacob (1988) investigated the development of *T. stercorea* over a range of constant temperatures and humidities to determine its potential as a pest. Tigar and Pinniger (1996) determined its susceptibility to pirimiphos-methyl and malathion, and Weinzierl and Porter (1990) examined the resistance of a strain from Illinois to the same chemicals. The current article examines the phenology and spatial distribution of this species in bulk stored grain.

Materials and Methods

Storage Situation. We studied infestations of *T. stercorea* in barley stored on a farm in northwestern Minnesota (Marshall County), in corn stored on 2 farms in southern South Carolina (Bamberg County and Barnwell County), and in wheat stored at a seed processing plant in north-central Florida (Levy County). Storage was in galvanized steel bins ranging in capacity from ≈120 to 350 m^3. The barley (160 t) was harvested in 1982 and had been stored for ≈4 yr when the insect population was sampled (Subramanyam and Harein 1990). Trapping in the corn and wheat began shortly after storage and continued until the grain was removed from the bins. The South Carolina

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study spanned 2 storage seasons (grain harvested in 1992 and 1993). Each year, the bin in Bamberg County was filled to near capacity and contained ≈83 t of corn. This corn was sprayed with malathion as it was unloaded from a wagon into the auger that conveyed it to the loading port on top of the bin. In 1992, the bin in Barnwell County was filled to ≈80% capacity (148 t), but in 1993, it was filled only about halfway (97 t). In both years, a 1% malathion dust was applied to the grain by hand as it moved up the auger into the bin. The bin in Florida was about two-thirds full of wheat (67 t), which had been air dried in wagons to 11.8% moisture content before storage in late July 1997. The walls and floor of the bin had been sprayed with Tempo (cyfluthrin) in June, after which it was used to store a small quantity of mixed grain (oats and rye), which was fumigated with phosphine and removed shortly before the wheat was loaded. The wheat was fumigated in late August by placing aluminum phosphide tablets on the grain surface and in the aeration duct, after which the duct was sealed.

Grain Temperature, Moisture Content, and Malathion Residue. These parameters are reported only for the South Carolina locations. Temperature was measured and recorded by means of an Easy Logger Field Unit (model FA-110) and TP10 thermistor temperature probes (Omnidata, Logan, UT). The unit's D-cell batteries, which required replacement every month, were replaced by 2 gel cells backed up by a solar panel on the bin roof. The gel cells are small rechargeable batteries, and the solar panel provided low-level (trickle) charging during periods of sunshine. With this arrangement, the batteries did not require servicing during the storage period. The Easy Logger was protected by a lightning arrester mounted inside the bin and wired to the solar panel, the logger, and to a copper ground rod adjacent to the bin. Temperature was measured every 10 min, and hourly averages were recorded on a data storage module (Omnidata DSM100) for later downloading to computer storage. Nine temperature probes arranged along the north-south and east-west diameters of the bin measured grain temperature at various points near the surface of the bulk (Fig. 1 A and B). One probe was located at the center of the bin, 4 at a distance of ≈15 cm from the bin wall, and 4 halfway between the center and the wall (either 1.4 or 1.8 m from the center, depending on the diameter of the bin). Each probe was secured with tape to a 38-cm length of 1.8-cm dowel rod, bluntly pointed at one end. The rods were pushed into the grain so that the sensor, which rested in a shallow groove near the pointed end, was 18 cm below the surface.

For each sensor, the recorded hourly mean temperatures were averaged, using the SAS means procedure (SAS Institute 1988), to obtain daily means, and these in turn were averaged to obtain weekly means. Weekly minimum and maximum temperatures were also determined for each sensor, using the SAS means procedure. Mean, mean minimum, and mean maximum grain temperatures (±SE) for the bin were then calculated by averaging the weekly means, the weekly minima, and the weekly maxima for the 9 sensors in the grain.

At weekly intervals, we took one 0.5-liter sample of grain from the surface next to each temperature probe for measurement of moisture content and malathion residue. The samples were held (24–48 h) in sealed polypropylene jars until moisture content could be measured with a Motomco model 919 Automatic Grain Moisture Tester (Dickey-John, Auburn, IL). Malathion residue was determined using the general method for organophosphates, as described by Arthur et al. (1988). Malathion residue was determined at irregular intervals during the 1st storage season (1992–93) but was determined weekly during the 2nd season.

Measurements of moisture content and malathion residue were entered in Microsoft Excel 97 (Person 1997) spread sheets for calculation of descriptive statistics. Malathion residues were fitted to two-parameter, single exponential decay curves, using SigmaPlot (SPSS, Chicago, IL).

The spatial distribution of grain temperature and moisture content were mapped by contour analysis (Arbogast et al. 1998) using Surfer (Golden Software, Golden, CO), with radial basis functions, multiquadric algorithm for interpolation. This is a flexible algorithm that provides good overall interpretation of most data sets (Keckler 1995).

Insect Trapping in Barley (Minnesota). The traps were acrylic plastic grain probe traps (37 cm long by 2.5 cm o.d.) (AgriSense Grain Probe, Thermo Trilogy, Columbia, MD), which were used as pitfalls without bait. The surface of the barley was divided into 4 concentric strata with radii of 0.04, 0.61, 1.83, and 3.66 m. Sixty traps were divided among the 4 strata in proportion to area, with the innermost containing 1 trap (Fig. 1D). The remaining strata, from next innermost to outermost, contained 2, 13, and 44 traps. One trap, for which the data were missing, is not indicated in the figure. Trap positions within strata, with the exception of the innermost, were assigned at random (Subramanyam and Harein 1990). The traps were inserted into the grain with the tops just below the grain surface, and insects were removed weekly from 20 August to 2 October 1986.

Insect Trapping in Wheat (Florida). The traps were AgriSense Grain Probes that had been modified for automatic counting (Shuman et al. 1996), but the insects were also removed at weekly intervals, counted manually, and identified to species. The traps were inserted into the grain with the tops just below the grain surface and were evenly spaced around the center of the bin in 2 concentric circles with radii of 0.9 and 1.8 m (Fig. 1C). There were 4 traps in the inner circle located north, east, south, and west of the center, and 4 traps in the outer circle located northeast, southeast, southwest, and northwest of the center.

Insect Trapping in Corn (South Carolina). The traps were polyethylene grain probe traps (Storgard WB Probe II, Trécé, Salinas, CA), which were used as pitfalls without bait. In 1992, 5 traps were arrayed with 1 at the center of the bin and 1 each north, east, south, and west of the center, halfway between the center

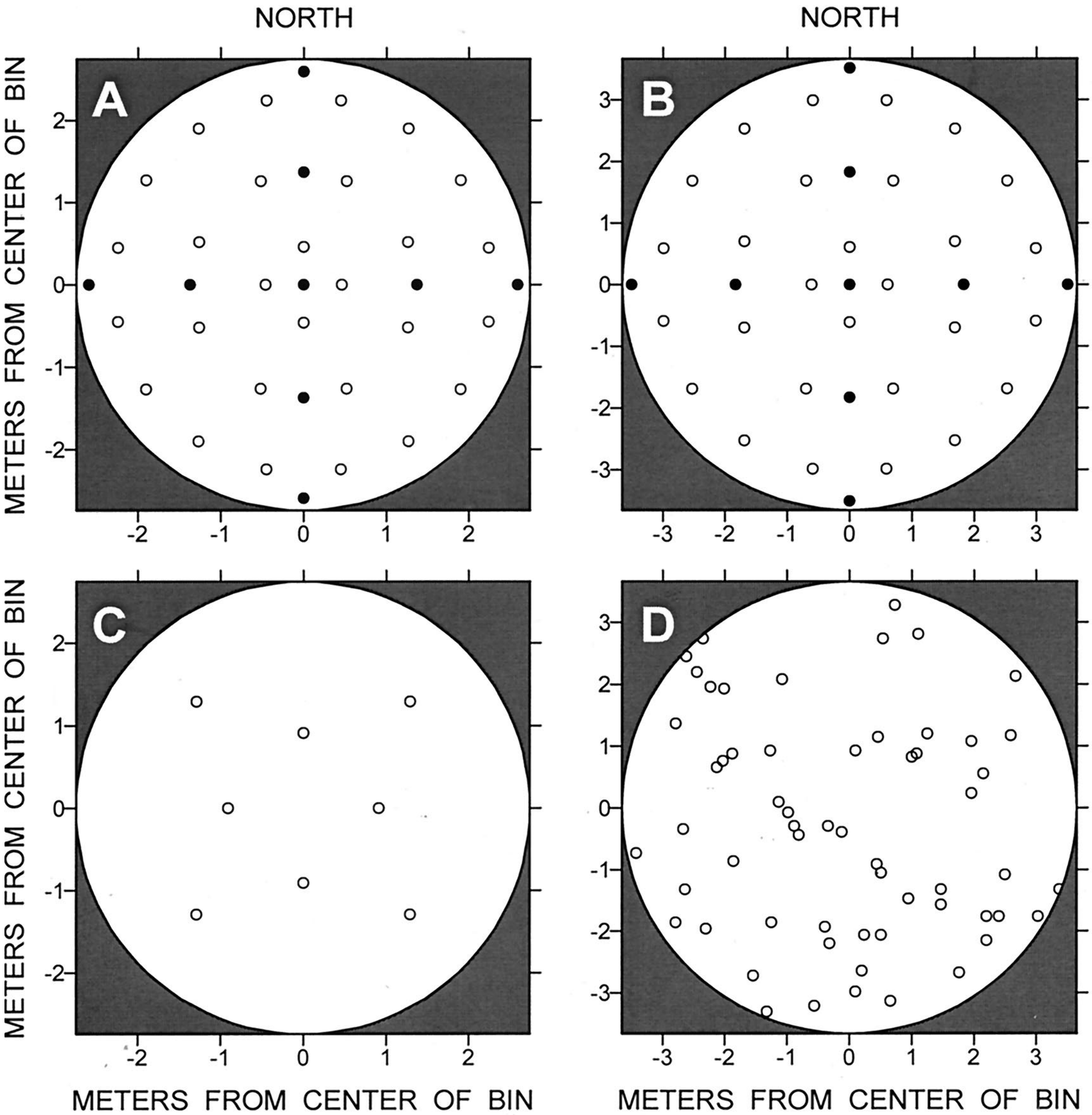

Fig. 1. Layout of traps (open circles) and temperature sensors (solid circles) in grain stored in steel storage bins. (A) Corn, Bamberg County, SC. (B) Corn, Barnwell County, SC. (C) Wheat, Levy County, FL. (D) Barley, Marshall County, MN.

and the bin wall. In 1993, 28 traps were evenly distributed around the centers of the bins in 3 concentric circles with radii 0.17, 0.50, and 0.83 times the radius of the bin (Fig. 1 A and B). There were 4 traps in the inner, 8 in the middle, and 16 in the outer circles. The traps were emptied at weekly intervals and returned to the same locations.

Analysis of Trap Catch. Insect counts were entered in Microsoft Excel 97 spreadsheets for calculation of descriptive statistics. The ratio of variance to mean was calculated as a measure of dispersion (Southwood 1978). For regular distributions, this ratio has a value of 0, and for Poisson (random) distributions it has a value of 1. It increases in value as distributions become more aggregated, so its departure from unity provides a measure of aggregation. An index of dispersion (I_D = variance (n-1)/mean) was calculated to test the null hypothesis that variance/mean = 1 (distribution of trap counts is Poisson) (Southwood 1978).

The spatial distribution of trap counts was mapped by contour analysis, using the same methods that were used for temperature and moisture content.

Correlation and Regression. The relationship of trap catch to weekly mean grain temperature, and to percentage grain moisture content was examined by correlation and regression analysis, using SigmaStat (SPSS, Chicago, IL). Because the data failed to meet all of the assumptions for a parametric test, Spearman's rank order correlation was used. Spearman correlation coefficients were calculated for each location, and for

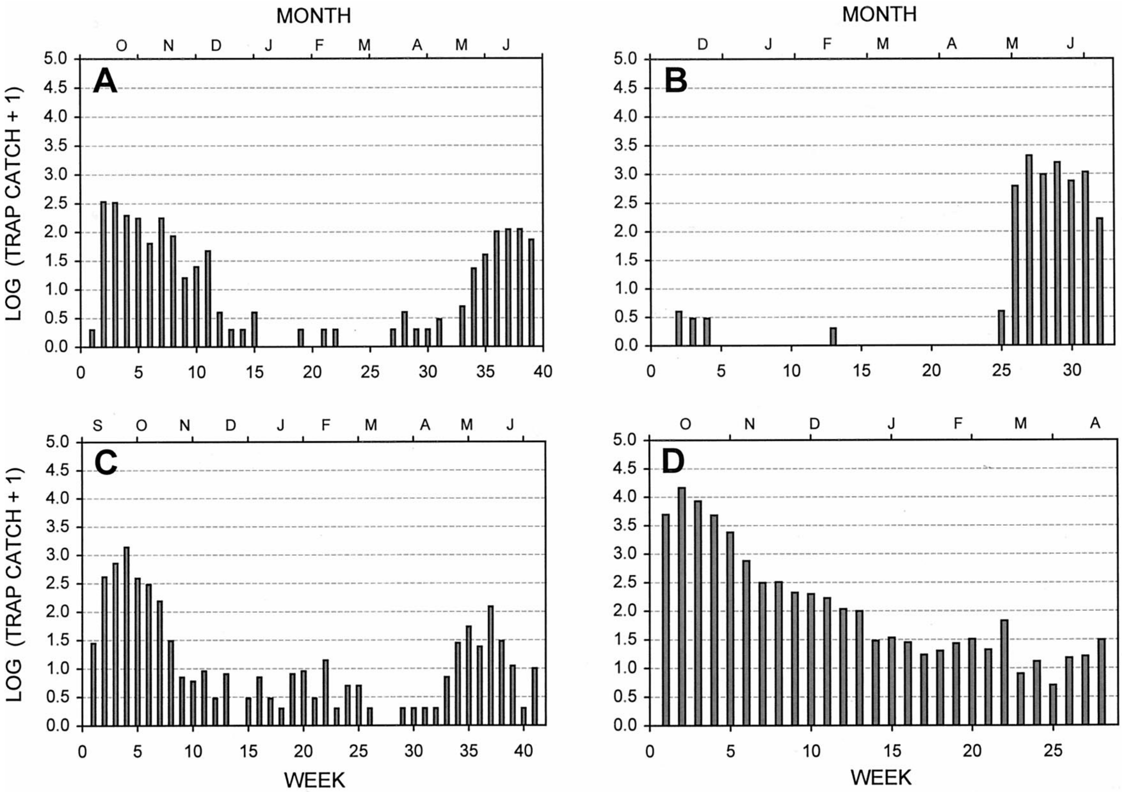

Fig. 2. Total numbers of *T. stercorea* captured weekly with 5 (A–B) or 28 (C–D) probe traps in corn stored on farms in South Carolina. (A) Bamberg County, 1992–1993. (B) Barnwell County, 1992–1993. (C) Bamberg County, 1993–1994. (D) Barnwell County, 1993–1994.

combined locations, in each bin over the storage period. A correlation coefficient was also calculated for the combined locations of both bins. The independent effects of temperature and moisture content on trap catch were examined by multiple (partial) linear regression, as described by Andrewartha and Birch (1954). Variation in trap catch, temperature, and moisture content over time were each fitted to a 3rd-order polynomial, with weeks of storage as the independent variable. The residuals calculated from these equations were then fitted to a multiple linear expression, with trap catch residual as the dependent variable. The coefficients of the 2 independent variables in this expression measure the independent effects of temperature and moisture content on trap catch.

Results and Discussion

Phenology (South Carolina). *T. stercorea* was frequently captured on the 2 South Carolina farms during 1992–1994, and the data collected over 2 storage seasons provided an opportunity to examine the impact of storage climate on the seasonal abundance of this species in traps. It was most abundant in September and October, shortly after the newly harvested grain was placed in the bins (Fig. 2). It declined in numbers as the grain cooled and became abundant again in May and June (Figs. 2 and 3). A late harvest on 1 farm during 1992 delayed storage until November (Fig. 2B). The initial peak in abundance that followed storage in September never occurred, and *T. stercorea* was not found in significant numbers until the following May. On the same farm in 1994, the grain was removed from storage in early April, before the spring peak in abundance (Fig. 2D).

Correlation analysis (Table 1) showed a strong association between trap catch and mean grain temperature, caused largely by parallel variation with season (Table 2). Mean temperatures fell below 15°C in December and rose above 15°C again in late March or early April (Fig. 3). Abundance of *T. stercorea* declined to very low levels during December and did not increase again until May (Fig. 2). Thus, trap catch responded immediately to declining grain temperature, but responded more slowly to increasing temperature, and there was a lag of ≈1 mo between the time the grain warmed to 15°C and the time that *T. stercorea* again became abundant. Mean trap catch for any week during the period from December through April, was usually <1 insect per trap, but a weak hot spot that occurred on the Barnwell County farm during 1993–1994 and persisted into December created an anomaly in this pattern (Fig. 2d). (A hot spot is region within a grain mass that has become heated by the

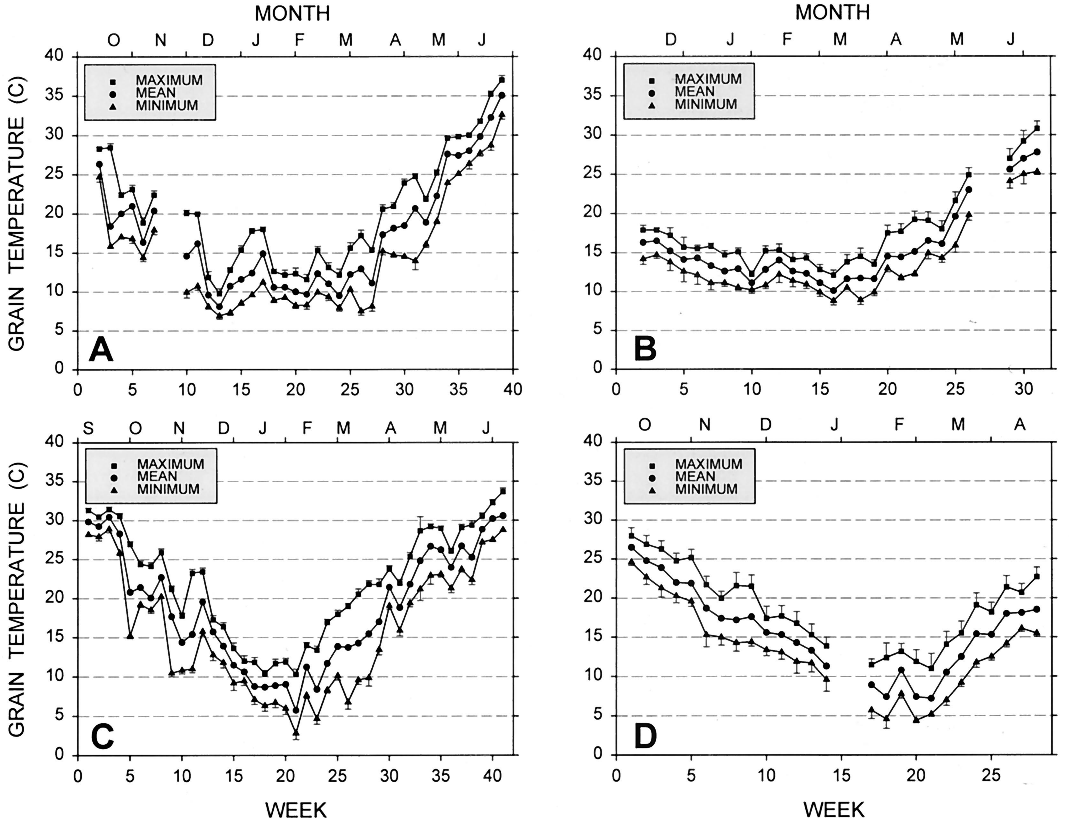

Fig. 3. Grain temperatures measured in corn stored on farms in South Carolina. (A) Bamberg County, 1992–1993. (B) Barnwell County, 1992–1993. (C) Bamberg County, 1993–1994. (D) Barnwell County, 1993–1994. Vertical bars indicate SE.

metabolic activity of insects, fungi, or the grain itself.) Although abundance still declined, it remained at somewhat higher levels. This can be attributed to unusually high rates of capture by 3 traps located within the hot spot.

Temperature influences trap catch both directly, through its effect on insect activity, and indirectly, through its impact on population growth. Thus, the observed seasonal variation in trap catch may have resulted from variation in activity level, changes in

Table 1. Correlation of grain temperature (T) and moisture content (MC) with numbers of *T. stercorea* captured by pitfall traps in stored corn

Bin	Position	Spearman[a]					
		N[b]	Coefficient	P[c]	N[b]	Coefficient	P[c]
Barnwell County	Center	28	0.765	0.000	30	−0.671	0.000
	East	28	0.537	0.003	30	−0.601	0.000
	North	28	0.608	0.000	30	−0.637	0.000
	South	28	0.536	0.003	30	−0.624	0.000
	West	28	0.538	0.003	30	−0.561	0.000
	All	140	0.596	0.000	150	−0.577	0.000
Bamberg County	Center	36	0.677	0.000	38	−0.014	0.934
	East	36	0.732	0.000	38	−0.133	0.423
	North	36	0.509	0.002	38	−0.074	0.656
	South	36	0.636	0.000	38	−0.029	0.862
	West	36	0.714	0.000	38	−0.042	0.801
	All	180	0.660	0.000	190	−0.082	0.262
Both	All	320	0.645	0.000	340	−0.173	0.001

Correlation of numbers captured in 1 wk with weekly mean grain temperature or weekly grain moisture content at trap positions, South Carolina, 1992–1993.

[a] Spearman rank order correlation coefficient for number of insects captured versus temperature or moisture content.

[b] Number of trap-weeks in analysis.

[c] Probability of a larger value of the coefficient when there is no true association.

Table 2. Temporal trends in trap catch, temperature, and moisture content; and independent influence of temperature and moisture content on trap catch

Regression diagnostics[a]	Polynomial (order 3) regression			Multiple linear regression of residuals
	$\ln(n+1) = f(t)^b$	$\ln(T+1) = f(t)^c$	$\ln m = f(t)^d$	$r_n = f(r_T, r_m)^e$
Barnwell County				
Adjusted R^2	0.650	0.812	0.848	0.066
F	93.3	201.3	278.0	5.942
P	<0.001	<0.001	<0.001	0.003
Bamberg County				
Adjusted R^2	0.686	0.866	0.787	0.035
F	138.8	385.9	233.2	4.209
P	<0.001	<0.001	<0.001	0.016

Change in number of *T. stercorea* trapped (n), mean grain temperature (T) and percentage grain moisture content (m) are expressed as third order polynominal functions of storage time in weeks (t). The residuals of n, T, and m (r_n, r_T, and r_m) from these polynomial relationships are fitted to a multiple linear model, which expresses the independent effects of temperature and moisture content on trap catch.

[a] Coefficient of determination adjusted for degrees of freedom (Adjusted R^2), F value corresponding to ANOVA statistics for regression, and probability (P) of a larger F value when there is no association between the dependent and independent variables.

[b] $\ln(n+1) = -0.382 + 0.238\,t - 0.0274\,t^2 + 0.000816\,t^3$; $\ln(n+1) = 4.551 - 0.367\,t + 0.00490\,t^2 + 0.0000896\,t^3$.

[c] $\ln(T+1) = 2.991 - 0.0495\,t + 0.000177\,t^2 + 0.0000601\,t^3$; $\ln(T+1) = 3.510 - 0.124\,t + 0.00381\,t^2 - 0.0000130\,t^3$.

[d] $\ln m = 2.596 + 0.0476\,t - 0.00321\,t^2 + 0.0000529\,t^3$; $\ln m = 2.813 + 0.00169\,t + 0.0000172\,t^2 - 0.00000564\,t^3$.

[e] $r_n = -0.0776 + 2.051\,r_T + 0.901\,r_m$. Only the coefficient of r_T is significant (t-test, $P < 0.001$). $r_n = -0.010 + 1.149\,r_T - 1.063\,r_m$. Only the coefficient for r_T is significant (t-test, $P = 0.006$).

population density, or both. Although we cannot yet quantify the relative contributions made by changing activity and changing population density to seasonal variation in trap catch, it is clear that change in population density had a significant effect. This is indicated by the lag time between grain warming and the resurgence of *T. stercorea* in the spring. Trap catch declined during the coldest months and increased again in the spring. We would expect such a winter decline to be caused by mortality, coupled with slowed or arrested oviposition and development, as well as by diminished activity. If the population density had remained static and trap catch had declined only because of reduced insect activity, we would expect trap catch to rebound almost immediately when the grain warmed to the threshold temperature for activity. Multiple linear regression (Table 2) provides further evidence of population decline during winter. This analysis suggested that the direct effect of temperature on trap catch, independent of other variables, is significant but weak. Although the temperature coefficients (2.051 and 1.149) are highly significant, they are small, and the coefficients of determination (0.066 and 0.035) indicate that the direct effects of temperature and humidity accounted for only ≈4–7% of the variation in trap catch.

In contrast to temperature, seasonal variation in neither grain moisture content nor malathion residue influenced seasonal variation in numbers of *T. stercorea* trapped (Figs. 2 and 4). Malathion residue declined exponentially throughout the storage period, and seems to have had little impact on *T. stercorea*, even at the highest level measured. Malathion residues were initially an order of magnitude higher, and were less variable, on the farm in Bamberg County (Fig. 4 A and C), where the chemical was applied as a spray, than on the farm in Barnwell County (Fig. 4 B and D), where it was applied by hand as a dust. Mean moisture content declined over the storage period, especially during the last 3–4 mo of storage, but usually did not fall below 12–13% (Fig. 4). Correlation analysis (Table 1) showed a negative association between moisture content and trap catch, which was significant only for the Barnwell County bin. This correlation resulted from the coincidence of moisture loss by the grain and population growth of *T. stercorea* during spring. These seasonal trends are apparent in Figs. 2 (A and B) and 4 (A and B), and in the regression equations relating trap catch or moisture content to weeks of storage (Table 2). But multiple linear regression (Table 2) showed that the direct effect of moisture content on trap catch, independent of other variables, is not significant.

Spatial Pattern in Barley (Minnesota). Numbers of *T. stercorea* captured in barley on the Minnesota farm showed a general decline in abundance over the six-week trapping period (mid-August to October). Mean weekly trap catch (±SE) ranged from 3.3 (±0.4) to 0.7 (±0.1). The number captured in any 1 trap ranged from 0 to 44 during the 1st wk and from 0 to 9 during the last. The trap counts were aggregated. Mean/variance ratios ranged from 14.0 to 3.5, and all were significantly >1. Contour analysis confirmed the aggregation and revealed its spatial pattern (Fig. 5 A–C). In August, when trapping began, the beetle population was concentrated in several centers joined by areas of lesser density, and a large area of the grain surface was devoid of captures (Fig. 5A). As the population declined, these concentrations of beetles disappeared, except for the largest, which was located in the southeast quadrant of the bin (Fig. 5 B and C).

Spatial Pattern in Wheat (Florida). During the first 2 wk of trapping (7–21 August), mean trap catch (±SE) increased from 2.9 (±1.2) to 34.3 (±21.2); and during this brief period, the spatial organization of the population changed markedly (Fig. 5D-E). Initially, there was a weak concentration of beetles near the southeast bin wall and a lesser concentration west of the bin center. Within a week, the pattern had changed to one dominated by a single large concentration centered around the south trap and involving most of the southern half of the grain surface. It is interesting that the south trap captured no *T. stercorea* during the 1st wk, but captured 171 during the 2nd. The mean/variance ratio increased from 23.3 to 645.5, and the indices of dispersion calculated from the ratios indicated a significant departure from Poisson. The traps were removed on 21 August, the bin was fumigated, and the traps were replaced on 18 September. Trap catch was significantly reduced by the fumiga-

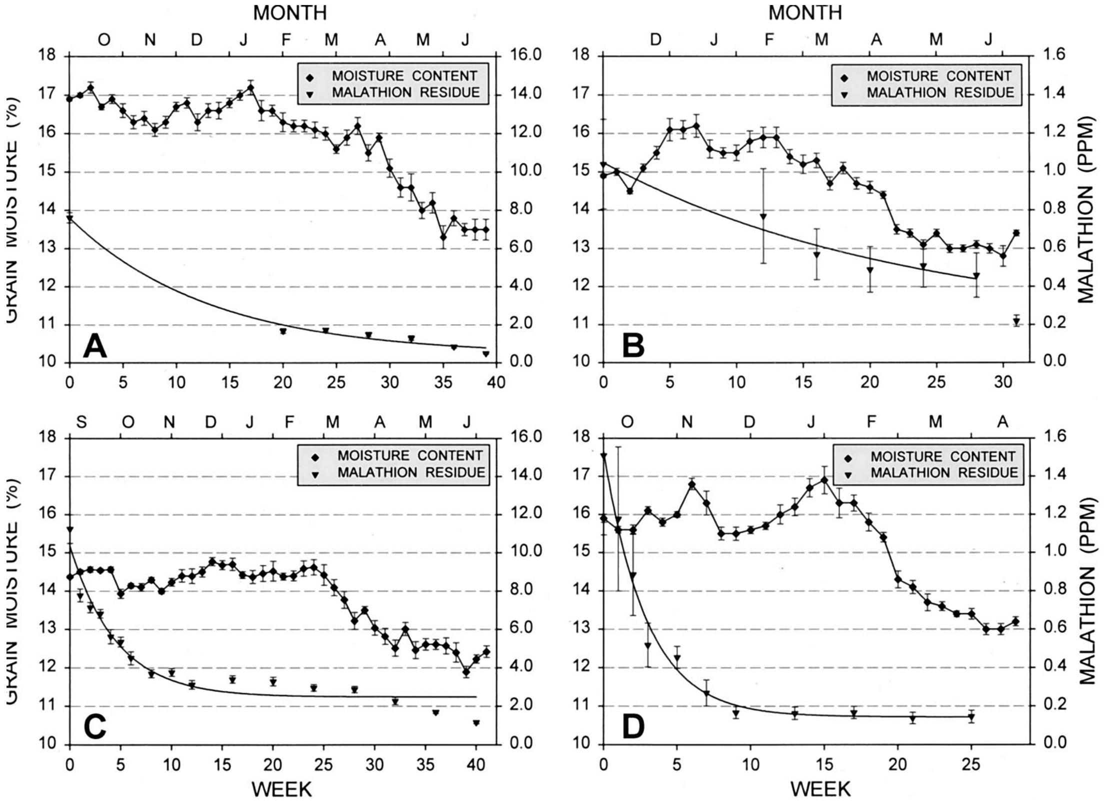

Fig. 4. Grain moisture content and malathion residues (mean and SE) measured on farms in South Carolina. (A) Bamberg County, 1992–1993. (B) Barnwell County, 1992–1993. (C) Bamberg County, 1993–1994. (D) Barnwell County, 1993–1994. Regression equations for the decay of malathion residues are as follows: (A) $r = 0.4157 + 7.1915e^{-0.0756t}$, Adjusted $R^2 = 0.987$. (B) $r = 0.1804 + 0.8682e^{-0.0431t}$, Adjusted $R^2 = 0.925$. (C) $r = 2.4760 + 7.8707e^{-0.2191t}$, Adj $R^2 = 0.934$. (D) $r = 0.1433 + 1.3925e^{-0.9890t}$, Adjusted $R^2 = 0.986$. Where r is malathion residue in ppm, t is time in weeks, and Adjusted R^2 is the coefficient of determination adjusted for degrees of freedom.

tion, but the population was not eliminated (Fig. 5F). Mean trap catch (±SE) during the first 2 wk after the traps were replaced ranged from 1.9 (±0.4) to 0.4 (±0.2) and the distribution of trap catch no longer differed significantly from Poisson. By the time the grain was removed on 16 October mean trap catch had increased to 2.3 (±0.8) and the distribution was again aggregated.

Spatial Pattern In Corn (South Carolina). The mean number (±SE) of *T. stercorea* captured per week for the entire storage period on the Bamberg County farm in 1992–1993 ranged from 27.0 (±9.6) in the central trap to 3.2 (±1.0) in the north trap. On the Barnwell County farm, mean captures per week ranged from 202.3 (±85.5) in the central trap to 5.8 (±2.4) in the north trap. In 1993–1994, the mean number captured per week on the Bamberg County farm ranged from 15.0 (±9.5) to 0.9 (±0.4), with most captures occurring in the 4 innermost traps. On the Barnwell County farm, the mean number of captures ranged from 438.0 (±26.5) to 7.5 (±0.6), and again most of the captures occurred in the 4 innermost traps.

The distribution of captures differed significantly from Poisson on both farms during both storage seasons whenever mean weekly capture exceeded 8.0 insects per trap, and sometimes when the mean was lower. We selected the 2nd storage season for contour analysis of spatial pattern because of the denser trap grid. It is clear from the preceding paragraph that mean captures for the storage period were higher near the bin centers. Contour analyses for selected weeks showed this quite clearly, and also revealed the dynamic nature of the spatial pattern (Figs. 6–7). The major population centers were apparently associated with the "spoutline" but expanded and contracted, possibly in response to local changes in temperature and moisture content. The "spoutline" is a region high in foreign material and broken grain that forms under the loading spout as the bin is filled, because lighter material does not flow as far and so remains near the center of the bin (Hoseney and Faubion 1992).

In the Bamberg bin (Fig 6), the warmest grain (>29.5°C) during the 2nd wk of storage occurred on the south and west sides of the bin and in the center (Fig. 6D). As the grain cooled, the isotherms moved southward until the warmest grain (>21.5°C) was against the south wall of the bin (Fig. 6 E and F). At the same time, the population center shifted slightly to

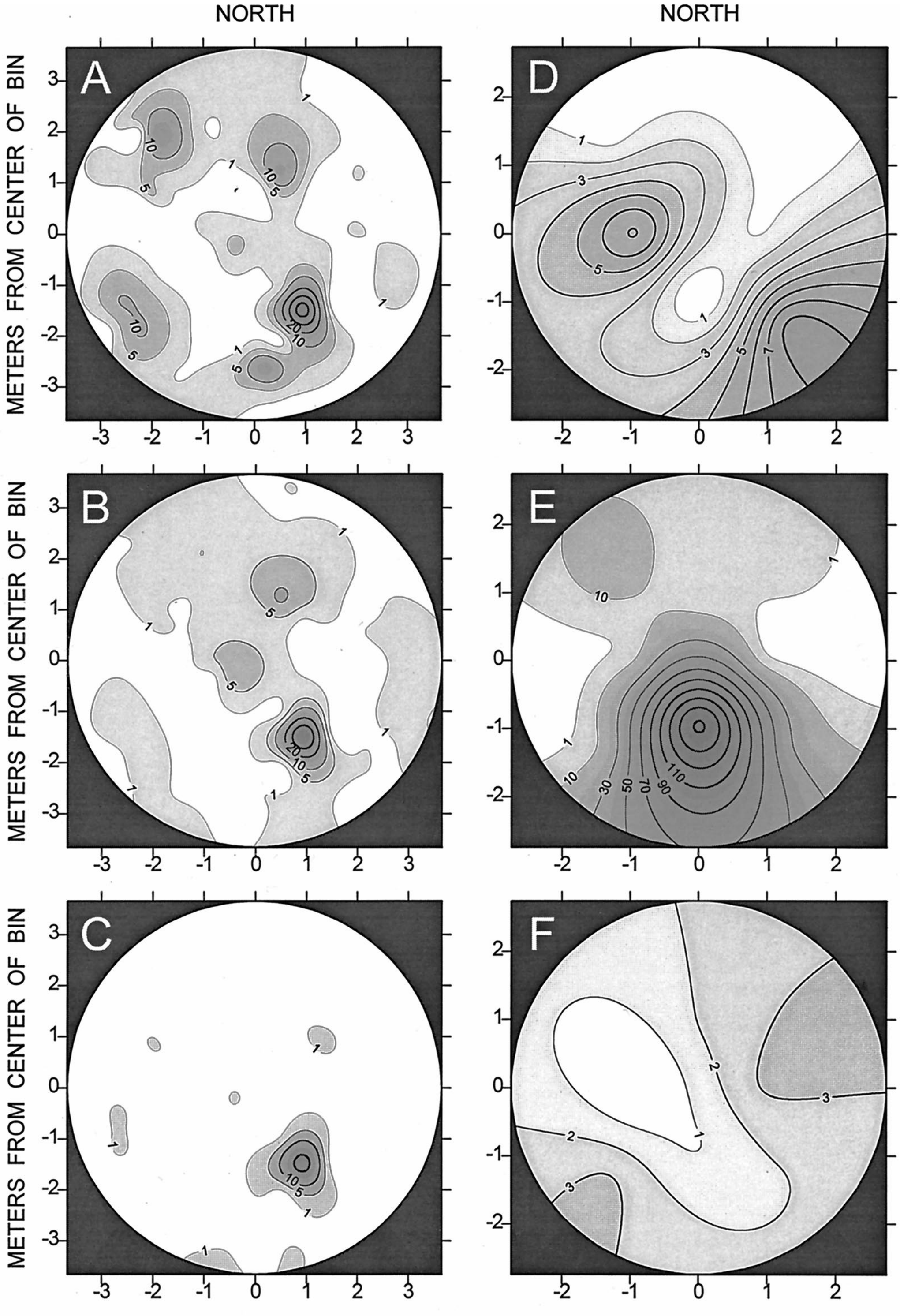

Fig. 5. Spatial distribution of *T. stercorea* in stored grain. (A–C) Barley stored on a farm in northwestern Minnesota after ≈4 yr plus 1 (A), 3 (B), and 5 (C) weeks of storage. (D–F) Wheat stored at a seed processing plant in Levy County, FL, during the 3rd (D), 4th (E), and 9th (F) weeks of storage. Contour lines indicate the numbers of insects captured during 1 wk. The wheat was fumigated with phosphine after the 4th wk.

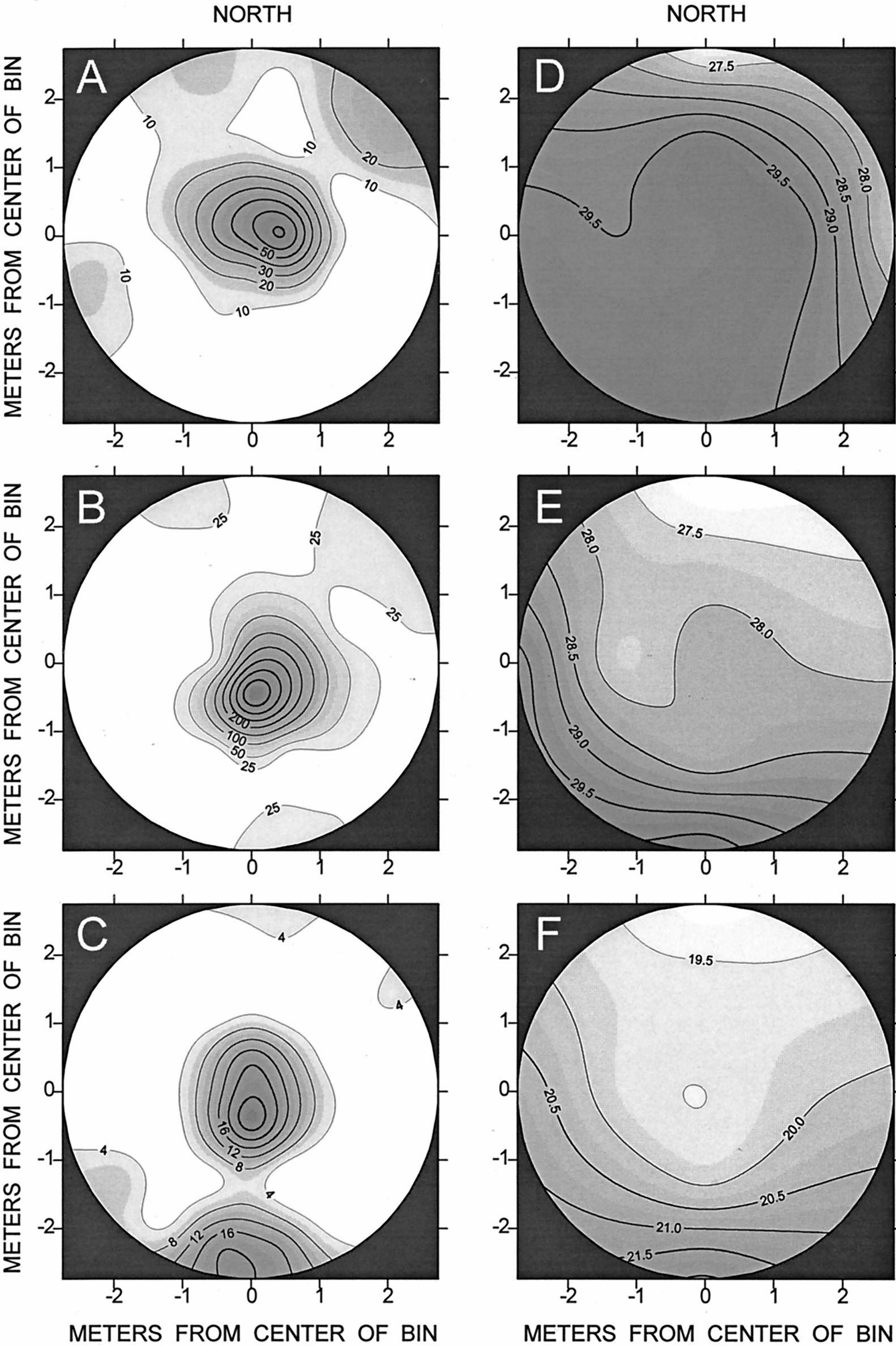

Fig. 6. Spatial distribution of *T. stercorea* (A–C) and grain temperatures (D–F) in corn stored on a farm in Bamberg County, SC, during the 2nd (8–15 September 1993) (A, D), 4th (22–29 September 1993) (B, E), and 7th (13–20 October 1993) (C, F) weeks of storage. Contour lines indicate the numbers of insects captured during the week (A–C) and mean grain temperature for the week (D–F).

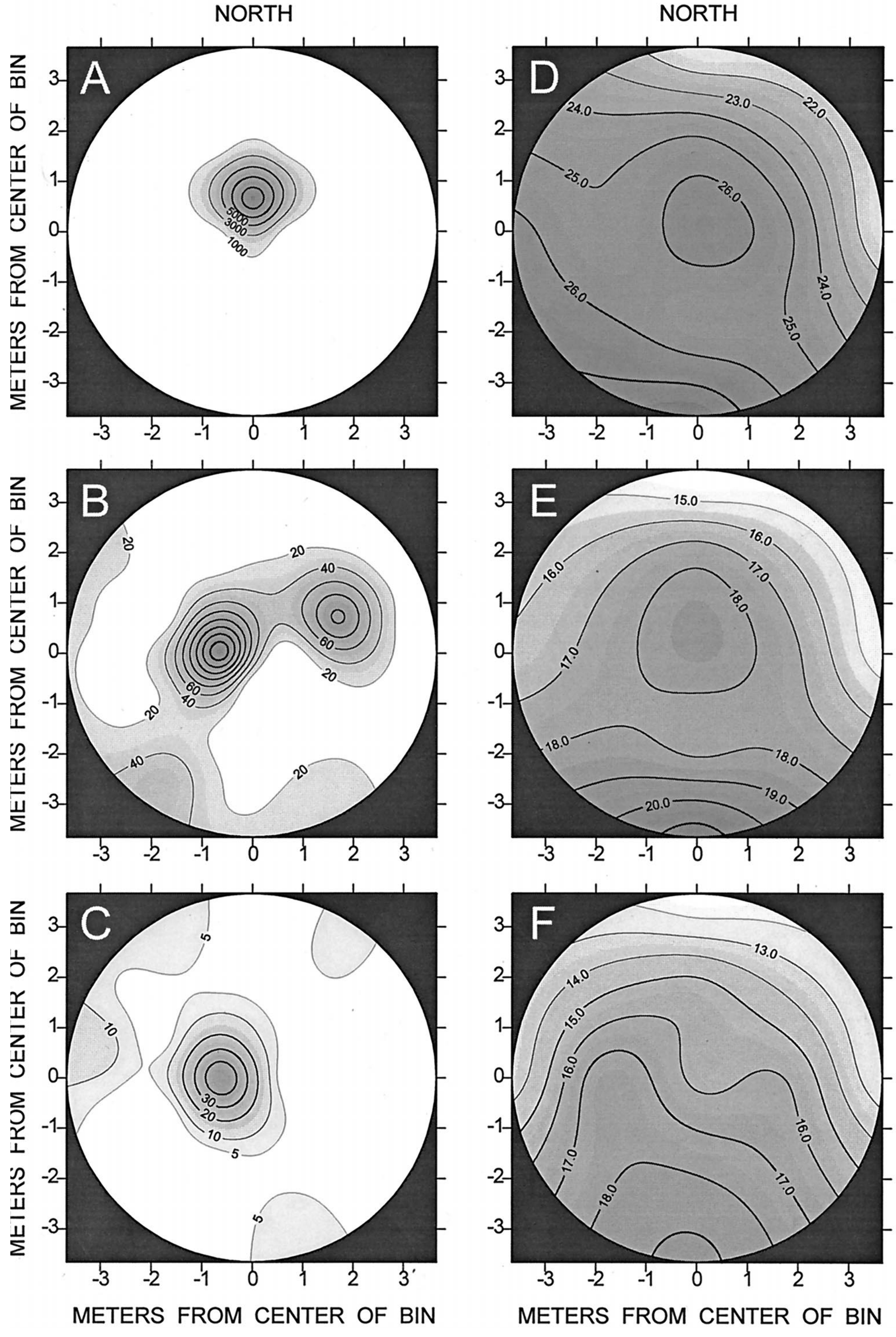

Fig. 7. Spatial distribution of *T. stercorea* (A–C) and grain temperatures (D–F) in corn stored on a farm in Barnwell County, SC, during the 2nd (29 September–6 October 1993) (A, D), 6th (27 October–3 November 1993) (B, E), and 11th (1–8 December 1993) (C, F) weeks of storage. Contour lines indicate the numbers of insects captured during the week (A–C) and mean grain temperature for the week (D–F).

the south and west, although it remained in the area occupied by the spoutline (Fig. 6B). It first intensified and then diminished as the grain in this area cooled. Finally during the 7th week, a 2nd center appeared against the south wall (Fig. 6C).

In the Barnwell bin (Fig. 7), extemely large number of *T. stercorea* were concentrated, along with other species, in an area just north of the bin center during the 2nd wk of storage (Fig. 7A). The mean grain temperature in this area was >26°C, but the warmest temperatures (>27.0°C) occurred along the south wall (Fig. 7D). Grain moisture content was high (>15%) over the entire grain surface, but was lowest in the vicinity of this concentration of insects (Fig. 8A). This changed markedly during the next 4 wk, and in fact a weak hot spot developed in this area and persisted into December. By the 6th week, *T. stercorea* had declined in numbers and the population center had spread out (Fig. 7B). The highest temperature (>21.0°C) occurred along the south wall, but a ridge of relatively higher temperatures extended northward beyond the center of the bin (Fig. 7E). The area of highest temperature (>18.0°C) and grain moisture content (>17.0%) coincided with the concentration of insects (Fig. 7 B and E and 8 B). By the 11th wk (December), the grain had become considerably cooler and drier, but a ridge of relatively higher temperature extended from the south wall toward the northwest (Fig. 7F), and the highest moisture content was >16.0% (Fig. 8C).

In conclusion, *T. stercorea* frequently infests stored grain and is often most abundant shortly after storage, as indicated by the literature already cited and the observations of the current study. This is not surprising, because it has been reported to infest standing crops in the field (Cotton and Winburn 1941, USDA 1986) and probably moves passively into storage with harvested grain. In the South, it is active and flies throughout most of the year, especially when temperature is above 20°C (Throne and Cline 1994), so infestation almost certainly occurs by active migration as well. The seasonal distribution in storage bins on South Carolina farms, with peak trap catch in the fall and spring, seems to follow changes in grain temperature and may be the usual pattern, at least in the southeastern states. But longer storage periods may produce additional peaks.

In the bins we studied, the pattern was not influenced by grain moisture content or malathion residue, but this may not hold in general. The grain moisture contents we observed remained relatively high. Drying to lower moisture content would certainly cause populations to decline. The lack of response to malathion residue can probably be attributed to resistance. Resistance to malathion and pirimiphos-methyl has been demonstrated in populations of *T. stercorea* infesting stored corn in Illinois (Weinzierl and Porter 1990). Also, Tigar and Pinniger (1996) found that malathion applied to corn at rates of 2–8 mg/kg gave <31% mortality of *T. stercorea* after 4 wk, even at the highest rate, and control had broken down completely by 12 wk.

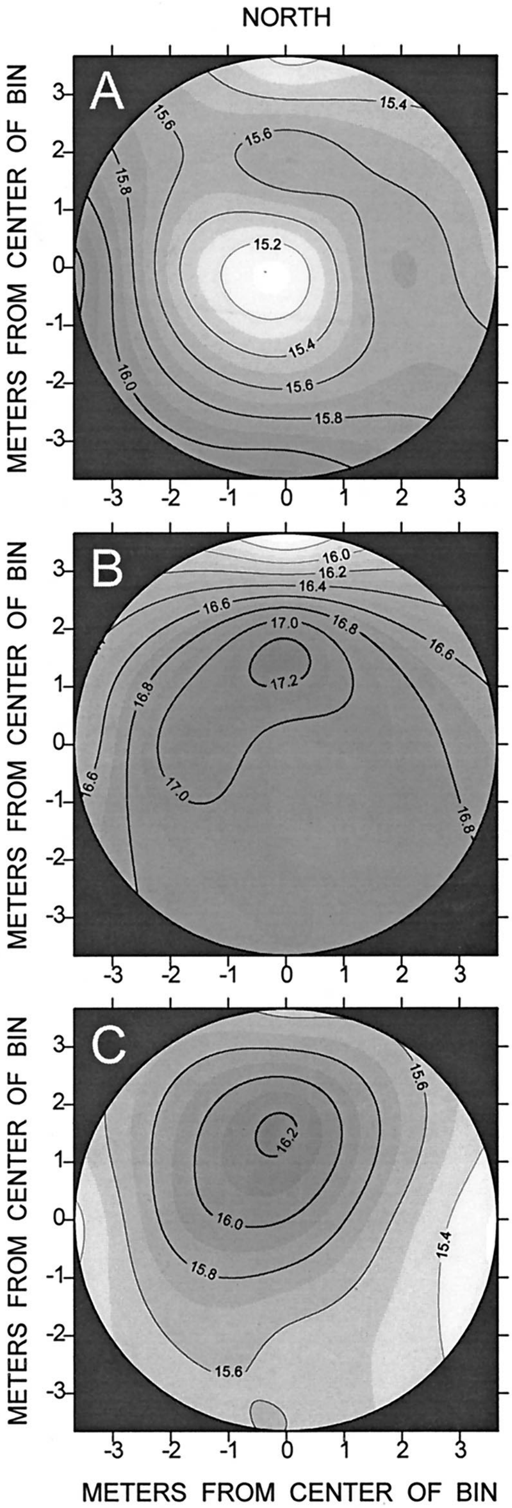

Fig. 8. Spatial distribution of grain moisture content in corn stored on a farm in Barnwell County, SC, after the 2nd (29 September–6 October 1993) (A, D), 6th (27 October–3 November 1993) (B, E), and 11th (1–8 December 1993) (C, F) weeks of storage.

Populations of *T. stercorea,* like those of other storage pests that occur in bulk grain, are not distributed randomly, but occur in aggregations, often comprising very large numbers of individuals. The nature and behavior of these aggregations has not previously been studied by spatial analysis, and some of the conclusions drawn for *T. stercorea* may apply to other species as well. In newly stored grain, *T. stercorea* occurs largely in 1 aggregation, or at least in a small number of aggregations, associated with the spoutline near the center of the bin. The distribution observed in the barley, which had been in storage for 4 yr, although clearly aggregated, was less organized and may be typical of long standing infestations. The spatial patterns we observed were dynamic, even on a very small time scale (week to week), and this is probably true for populations of storage pests in general. Numbers of insects in aggregations rose and fell, the areas involved expanded and contracted, the centers of aggregations shifted (but usually remained anchored to the area of the spoutline), and secondary centers appeared and disappeared. These changes seem to be in response to changing patterns of grain temperature and moisture content, and secondary centers of aggregation often occurred in warmer grain along bin walls.

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